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Final Report

MODELING FLIGHT SIMULATOR VISUAL/MOTION CUE EFFECTS ON PILOT PERFORMANCE; A SUMMARY

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July 10,1986

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1.0 Table of Contents

2.0 Acknowledgements

The author of this introductory document wishes to commend and thank the many contributors to this program. Perhaps, it was a lucky combination of the right people, time and place that resulted in successfully illuminating the simulation issues covered. It is important, therefore, to name the individuals involved.

Drs. Grant R. McMillan, the Technical Monitor, and Rik Warren of the Armstrong Aerospace Medical Research Laboratory and Dr. Edward A. Martin of the Aeronautical Systems Division aptly articulated their research needs and performed the experiments with the assistance of Systems Research Laboratory personnel.

Drs. William H. Levison and Greg L. Zacharias and their colleagues at BBN Laboratories, Inc. and Charles River Analytics, Inc respectively, applied their considerable and innovative modeling talents to the research, and generated the five volumes of research reports and associated papers.

This author had the pleasure of serving as the industry program manager and prime contractor. All parties named contributed to the direction and review of the effort. Also, I wish to thank Maj. Milt Miller of the 162nd Tactical Fighter Group/Fighter Weapons School at Tucson, Arizona for his valuable insights into piloting problems in low-level flight and his introspective thoughts on future Air Force combat roles.

3.0 Background and Purpose of This Report

The advent of the modern computer during World War II and its proliferation following that conflict has greatly enhanced the human thinking process. The words "model" and "simulation" are commonplace today and are used to describe mathematical formalisms usually implemented on a computer that mimes some intuitive thought. These models may be thought of as a preliminary theory of the process involved, because if developed properly, their results are subject to experimental verification.

The U.S. Air Force uses mathematical models extensively. For the effort described here, the Armstrong Aerospace Medical Research Laboratory has had as a goal the development of models for human performance. Specifically, these models are addressed at the effects on pilot performance of simulator motion and visual cues. The models are applied to understanding the usefulness of whole and partial body motion cuing devices and visual imagery generating equipment intended for training and/or engineering development. The motivation is, of course, to enhance the intelligent development and procurement of effective training equipment and engineering simulators. The present investigation grew out of prior successes in modeling these effects for simpler laboratory scenarios.

The purpose of this report is to introduce the reader to this research program by describing its goals, the approach followed in striving for these goals, and the products generated. It is prudent, also, to offer interpretations of the research results for users of such data (e.g., designers or procurers of training equipment) even though such suggestions cannot be soundly supported at this time.

The remainder of this report describes the research goals and approach followed, some fundamental concepts and definitions for visual and motion cuing research, and also contains a short introduction to the

and motion cuing research, and also contains a short introduction to the research reports.

4.0 Research Goals and Approach

This research program was initiated in 1981. At that time, the detailed knowledge of the effects on pilot performance of simulator characteristics was sketchy in both the motion and visual cuing areas. Some model development had taken place, mostly addressed to motion cuing. This background is reflective of the state of simulation technology at that time. Motion cuing devices and associated research had progressed through several generations of development as exemplified by the bibliography of Puig, Harris and Ricard in 1979 (ref. 1). In contrast, visual cuing devices for simulators at that time were mostly based on the television camera/modelboard concept, although sophisticated computer image generators were beginning to appear. Also, no visual cuing assessment similar to that of Puig existed because the visual cuing technology was still in its relative infancy.

On the side of military operations, particularly those of the Air Force, the high-threat battlefield was pushing tactics toward low-level flight in order to enhance survivability and fighting effectiveness. To sum up, three factors greatly impacted the course of this research. They are:

1) Optimistic early results from models describing motion cue effects on pilot performance

2) The advent of sophisticated and flexible visual cuing devices for simulators

3) The awareness that future military operations require flight at low level

The important ingredients that comprised our approach considered the above and the fact that there exist a myriad of variables that affect

of our approach were:

1) Build on the models already developed for motion cue effects on pilot performance by striving to understand the universal principles involved.

2) Extend these models to visual cue effects and expand their applicability by select experimental verification.

3) Focus these model results on key problem areas of low-level flight.

The above ideas are more fully discussed in the experimental plan (ref. 2).

5.0 Fundamental Concepts

The mathematical models that were developed under this program attempt to describe the performance of pilots in specific tasks. The tasks chosen were those of terrain following where the terrain was initially constructed of a simple flat surface. The performance metrics computed by the models are system metrics, i.e., aircraft/terrain tracking error, although other parameters such as control activity are also computed. The initial work addressed a fully-trained pilot performing a stabilized tracking task. Workload was not assessed except insofar as attention sharing allocation in the models was selected. Also, these models were validated using laboratory test scenarios in the context of simulated motion and visual cues.

An important issue to recognize is that in the formulation of a model, the stimulus/perception relationships are analyzed mathematically and the results form the perceptual portion of the model that converts the stimulus into the perceived information required to perform the task. By this formulation, we are assuming that the pilot has somehow learned the stimulus/perception relation, but does not necessarily understand nor utilize the mathematical basis for it.

The title of this program "Modeling Flight Simulator Visual and Motion Cue Effects on Pilot Performance" means that the research has been directed toward simulated visual and motion cue effects. In all cases, therefore, this means that a device other than the real one has been used in the research. For example, the G-seat in lieu of a real moving aircraft and an image generator rather than the real out-the-window scene.

This means that for a motion experiment, a drive logic was employed to move the G-seat elements. For a visual cue experiment, elements of a real scene were selected to provide the desired information in lieu of that embedded in a real scene. The choice of these simulator characteristics was always based on considerations of the information needs versus the hardware constraints.

5.1 Motion Cuing Overview

Motion cues to a pilot can be expressed as two vectors representing the angular and linear acceleration of the body. The actual stimulus is the force distributed on the body, but because this is inconvenient to express, the resulting accelerations in unit of radians/sec^2 and ft/sec^2 are used. These quantities are only a function of the aircraft movement and the earth's gravitational force, and are easily computed in most flight simulator computers. The goals of motion simulation are, therefore, the representation of these accelerations to a level adequate to perform the task while maintaining movements within hardware constraints such as travel limits. The effective motion device accomplishes these two goals.

5.2 Visual Cuing Overview

The case with visual cuing is more complex because our visual sense is more complex. While with motion cues, a definition encompasses only two quantities, visual cues are any array of visible light patches that can be interpreted as a prompt to action. As such, the possible cue arrays are enormous. Four elements are implied in the preceding definition: 1) an array of light patches, 2) the light patches are visible to the human observer, 3) they offer at least one interpretation of the desired

information and 4) the desired information is sufficient for accomplishing the given task.

In our research, we have constructed our displays so that they are always visible and subject to a mathematical representation to arrive at an interpretation. We have purposely avoided the use of ambiguous displays (those that permit multiple, conflicting interpretations) and displays that are just barely visible. We have included those that contain redundant information and facilitate multiple, but consistent, interpretations. We have also tried to design visual cue experiments that encompass the broad range of visual cue complexities. A way of expressing this complexity is the contiguous scan line spectrum of the whole or part of the image. Taken this way, our experiments addressed cues that had narrow, sharp line spectra (arrays of lines on the surface) to broad, indistinct spectra (random texture on the surface). The reason for this choice was to extend the applicability of the resulting models, but also to cover the range of attention required. We expect that the line images require a short gaze time to interpret. The texture images, however, should require a longer time owing to the need to interpret their relative movement. This is important for later assessments of visual attention workload, an issue so important to the performance of low-level flight.

6.0 Introduction to the Research Reports

Five reports were generated during this effort. They are listed as references 2 through 6. The following paragraphs contain a short synopsis of their contents.

Ref. 2; "Experimental Plan for Study of Visual/Motion Cue Effects on Pilot performance"

This document describes the technical plan that encompassed the initial model predictions for purposes of experimental design, and the experimental designs themselves, as arrived at by team consensus at the program's inception.

Ref. 3; Volume I, "Models for the Effects of G-seat Cuing on Roll-Axis Tracking Performance"

This report describes a model of G-seat motion cue effects on pilot performance in a roll axis tracking task using drive algorithms based on vehicle acceleration, velocity and position of the roll axis. The G-seat used was an advanced, second generation type, and the visual cues employed were those provided by a simple ADI-type display. Performance equivalent to that obtained in a previous experiment utilizing whole body motion cuing was experimentally demonstrated and modeled.

Ref. 4; Volume II, "Use of Linear Perspective Scene Cues in a Simulated Height Regulation Task"

This report describes a model of pilot performance in a simple height-holding task over a flat surface. The experimental arrangement consisted of a display of an infinitely-long roadway stretching ahead of the flight path. The roadway was depicted by two parallel lines in the flat surface. The validation experiments were conducted fixed-base, i.e., without motion stimuli. The experimental results were successfully modeled.

Ref. 5; Volume III, "Modeling the Pilot's Use of Flight Simulator Visual Cues in a Terrain-Following Task"

This report describes a model of pilot performance in a height regulation task with two additional displays. One was a combination of the roadway display (ref. 4) and a texture field. The second was a texture field alone. The validation experiments were also conducted fixed-base, i.e., without motion cue stimuli. The results for the combined display showed essentially the same performance as with the roadway display. Performance with the texture display resulted in twice the height tracking error compared to that with the roadway display. The results were successfully modeled. They demonstrate the dominance of linear

perspective cues over motion perspective cues involving texture. They also point to the existence of perceptually-risky environments which consist of random features interpreted only by the slower mechanisms of motion perspective.

Ref. 6; Volume IV: "Design and Performance Analyses for an Image-Flow Terrain-Following Guidance System"

This document reports an unexpected fallout of the program. Models describing visual cue effects on pilot performance can lead to a class of machines that function something like the human does, but better. The model for the use of motion perspective involving texture cues results in a body of mathematics that when integrated into a flight guidance system appear able to automatically and safely control a low-level flight path using only a passive digitizing camera pointed generally ahead of the aircraft. This discovery has important implications for automating terrain-following flight without the use of stealth-degrading measurement concepts such as radar.

The report derives the important parameters of a terrain measurement/flight guidance system based on the use of a digitizing camera and a guidance computer. This concept relies on the sensing of relative motion of surface features and does not require surface feature identification. The system analysis shows the potential for acceptable performance and demonstrates the theoretical feasibility of such a concept in automating low-level terrain-following flight using passive sensors.

7.0 References

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